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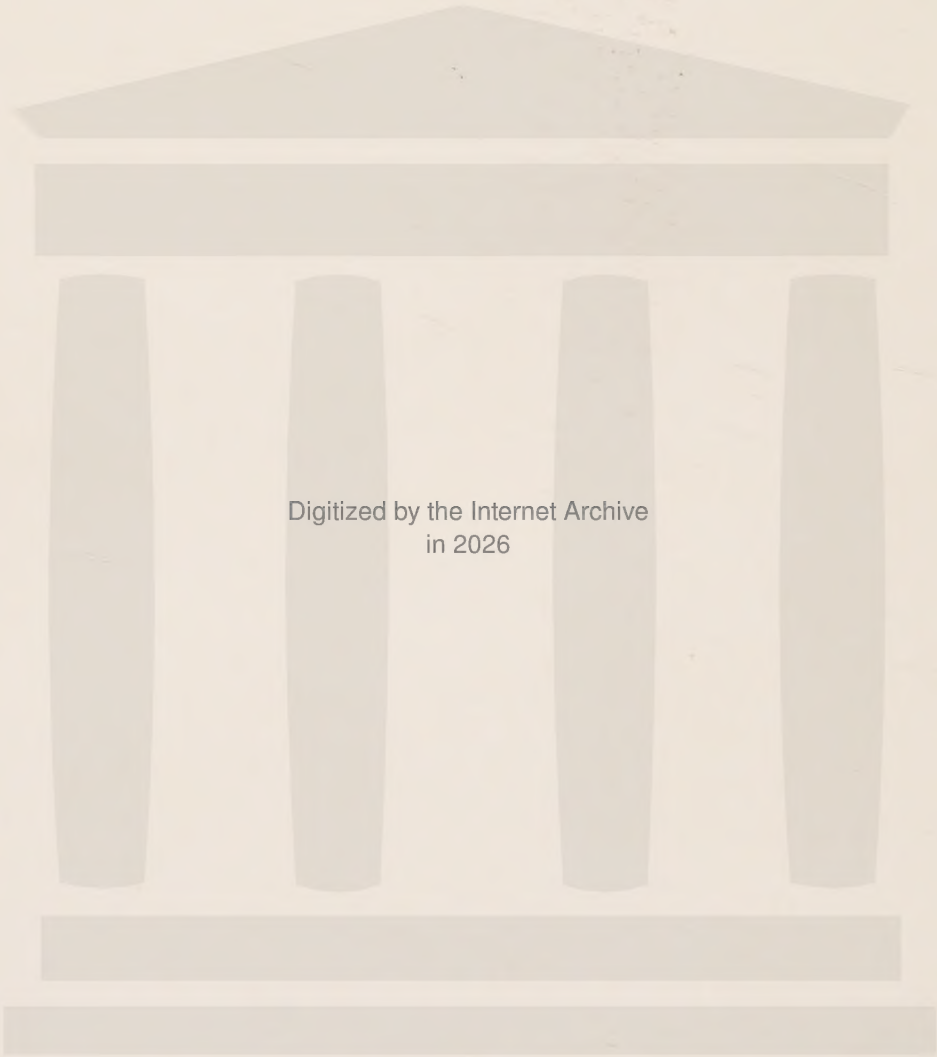
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Republic of South Africa
Department of Environmental Affairs and Tourism
SEA FISHERIES RESEARCH INSTITUTE

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MISSION OF THE SEA FISHERIES RESEARCH INSTITUTE

The Sea Fisheries Research Institute advises on the optimal utilization of living marine resources and the conservation of marine ecosystems by conducting and supporting relevant multidisciplinary scientific research and monitoring in the marine environment. Sustainable utilization and the need to preserve future options regarding the utilization of marine ecosystems and their resources are guiding objectives in the research and advice of the Institute. In order to achieve its goals, the Institute advises and interacts with decision-makers, the fishing industry, interest groups and the local and international scientific community. The Institute conducts its activities in an open and cooperative manner, functions within the Department of Environmental Affairs and Tourism and strives for excellence in its research and advice.

1. INTRODUCTION

THE year under review has been an exciting one — a year characterized by both uncertainty and hope for the future. The developments in South Africa provide enormous challenges and opportunities for Sea Fisheries and the Research Institute in particular. The structural and strategic changes which were implemented in the Institute a few years ago fortunately enable us to adapt to the new operating environment and to make a meaningful contribution to the furtherance of the aims of the Reconstruction and Development Programme (RDP) of the government of national unity. Indeed, all the Institute's activities are compatible with the RDP. Moreover, various new research initiatives which have been formulated by the Institute in partnership with a broad cross-section of the South African marine science community will ensure that resource-related research becomes even more relevant to the needs of a changing society.

The format of this, the third issue of *Research Highlights*, deviates somewhat from preceding issues. The section on environmental and ecological studies has been replaced by one which is more reflective of the supporting research undertaken within the Institute as a whole. I believe that this change will provide the reader with a better overview of our activities. Notwithstanding this, the sections which follow are, through necessity, only highlights of the work and are not intended as a comprehensive all-inclusive account of the research. Readers seeking detail are referred to our house journal, viz. the *South African Journal of Marine Science*, and other international scientific journals.

In the last issue of *Research Highlights* it was mentioned that work had commenced on the development of a multispecies approach for the management of pelagic fish. Good progress has been made with this and brief details of the modified management procedures for anchovy *Engraulis capensis* and pilchard (sardine) *Sardinops sagax* are provided in this issue. These procedures have been implemented with effect from January 1994 and hopefully will facilitate more responsive management of the main pelagic species.

One of the major challenges during the year under review has been the development of an appropriate research programme to assess the resource biological and socio-economic consequences of commercially longlining Cape hakes *Merluccius capensis* and *M. paradoxus*. Central to this research is the selectivity patterns of the trawl v. longline fisheries, and early in 1994 a workshop, which included all interested and affected parties, took place, from which emerged an agreed *modus operandi*.

The growth and production rates of West Coast rock lobster *Jasus lalandii* were again low during 1993. This remains a major source for concern. Model simulations show that current levels of harvesting cannot be sustained if growth rates do not improve. The precise cause of the slow growth rates remains elusive and poses an urgent research challenge, the outcome of which could influence future management of the resource significantly.

I do not propose to repeat the essence of the highlights in this introduction, as most are sufficiently brief already and need to be viewed within context. What I would like to do is to invite all stakeholders in our living marine resources to provide constructive comments on any of those aspects of the research which have been highlighted and feedback as to their perceptions about the utility of the *Research Highlights* series.

* * *

2. STUDIES ON RESOURCES

2.1 Pelagic fish

ANOTHER year of exciting, relevant and high quality research on pelagic fish was experienced during 1993, with particular emphasis on anchovy and pilchard. A substantial revision was undertaken of the management procedures for these quota-controlled (by means of Total Allowable Catch *TAC*) species. The revisions involved full reassessments of the key population dynamics parameters for both species and the development of a new simulation or operating model of the pilchard resource. A feature of the revised management procedures is that separate pilchard *TAC*s are now set for by-catch and directed catch and, in determining the former, the anchovy *TAC* and recruitment of 0-year pilchard are now considered. A second feature of the exercise was the close consultation between the Institute and the pelagic fishing industry in attempting to develop procedures which best met the needs of the industry without endangering the sustainability of the two stocks.

The anchovy results from the routine May recruitment survey were highly unusual. The biomass estimate of 204 000 tons was well below average, but the fish were very small and with an average mass of only 1,93 g, less than half the normal mass of recruits on these surveys. This was probably a result of late recruitment, but it meant that the number of recruits, which is the parameter used in the operational management procedure, was high, resulting in an increase in the anchovy *TAC* to 360 000 tons. At the time, concern was expressed that the very small size of the recruits could lead to high mortality. This appears to have happened, and the November 1993 estimate of anchovy spawner biomass was only 751 000 tons, close to half that of the previous year.

The pilchard results were more consistent, and the recruitment estimate of some 23 billion fish, by far the highest estimate on the hydroacoustic records (Fig. 1), was followed by an estimated increase in spawner biomass to 464 000 tons in November 1993. This value was also the highest on record, although only marginally up on the 441 000 tons estimated in November 1991.

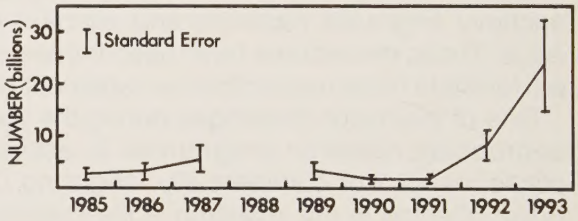


Fig. 1: Estimates of pilchard recruitment made on mid-year hydroacoustic surveys

As a result of these developments in the fish stocks, the pelagic sector was unable to catch its anchovy *TAC*, and the total catch for 1993 was < 236 000 tons, more than 100 000 tons below the *TAC*. In contrast, the pilchard by-catch and directed *TAC*s were filled without difficulty and, because of the large number of pilchard recruits, it proved very difficult to avoid exceeding the by-catch ceiling. The above scenario demonstrates the heavy reliance placed on the hydroacoustic estimates of pelagic fish biomass, and much research effort still goes into improving these estimates.

The Institute again occupied field stations at the most important pelagic landing sites on the West and South-West coasts, and the technical staff provided results of high quality on species composition and on size and age-structure of the commercial catches during the season. The necessity of sampling catches at all five sites is being investigated in a statistical study examining the estimation of species, length and age composition of catches. Although

no decision has yet been made, preliminary results suggest that one field station could possibly be closed, with savings in manpower and costs, without adversely affecting the results of the overall sampling exercise.

Another important area where substantial improvements are anticipated shortly is in age determination of both anchovy and pilchard, an important source of information in fisheries management. Some concern has been expressed about the criteria previously used to assign anchovy and pilchard to year-classes by examination of growth rings on their otoliths. The major uncertainty in this approach is distinguishing between annual rings and "false" rings. Support for the revised criteria has been obtained from an examination of otoliths for daily growth rings, which revealed an average of 349 daily rings between the postulated annual rings. In addition, the proposed new criteria independently identified the late and poor recruitment in 1993. Although some additional verification is still required, it appears that a substantial improvement in age determination, at least for anchovy, is imminent.

Research into the reproductive biology of anchovy and pilchard has continued, with particular emphasis on investigating the feasibility of applying the egg production method of biomass determination to pilchard. Results obtained from earlier experiments on determining the age of post-ovulatory follicles are being used to confirm the histological criteria applied to determine the age of females in the wild. In addition, histological analysis of the ovaries of female pilchard provided definite evidence of serial spawning in the species. These results will facilitate the application of the egg production method of biomass determination to pilchard. However, it still needs to be established, from the current Sardine and Anchovy Recruitment Programme (SARP), whether reasonably precise estimates of daily egg production can be obtained.

A further exciting development in the studies of reproduction in pelagic fish has been a joint project between the Institute, the Benguela Ecology Programme and the University of the Western Cape. The study has used physiological and biochemical indicators, with particular reference to the functioning of the endocrine system, to provide additional information on reproductive cycles, spawning seasons, age-at-first maturity and other features of interest.

2.2 Demersal fish

RESEARCH in 1993 focused on improved assessment of the Cape hakes and Agulhas sole *Austroglossus pectoralis*. Applications for permits to longline for hake continued to put pressure on management to reintroduce this form of fishing. Research emphasis was therefore directed towards improving our understanding of the biology and dynamics of the Cape hakes.

Central to the longline issue and the present research is the selectivity pattern of the hake-directed trawl fishery compared to that of a potential hake longline fishery. Kingklip-directed longline research in the 1980s showed clearly that the trawl and longline fisheries are likely to target different portions of the hake

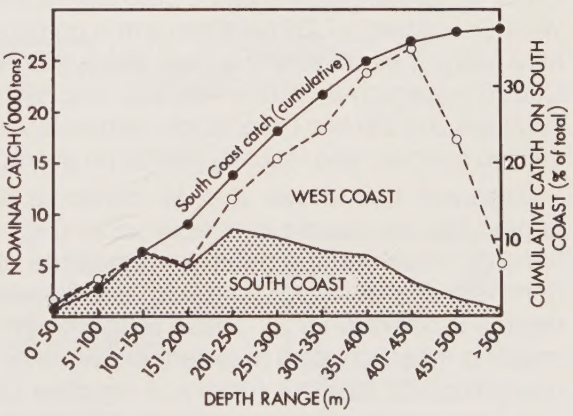


Fig. 2: Hake catches by depth range and area in the trawl fishery of 1992, showing the cumulative catch by depth on the South Coast

resource. The trawl fishery currently targets predominantly juvenile and early maturing hake, whereas the longline fishery selectively catches the older, more fecund fish. A complicating factor in any future fishery is that different types of longliners are likely to be employed, including offshore longliners operating on the shelf-edge and inshore longliners with limited range and fishing in depths shallower than 200 m. Analysis of the trawl data shows that the catch is predominantly made on the West Coast in water deeper than 300 m. In contrast, the South Coast catch approximates 30–40% of the total hake catch (Fig. 2) and the greater portion of it is made shallower than 200 m. Assuming that different longline fisheries are likely to operate, research is being directed at trying to understand the impacts such a fishery would be likely to have on the hake stocks on the West and South coasts.

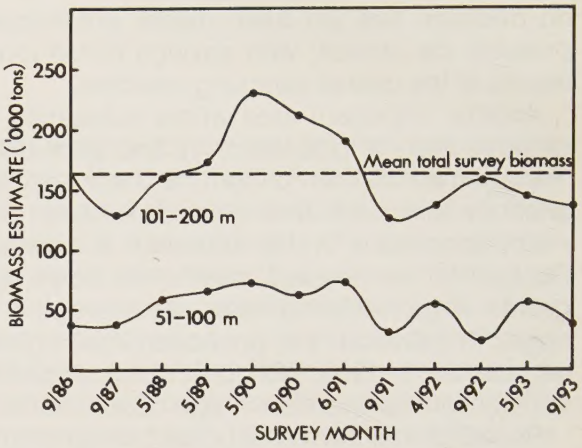


Fig. 3: Survey biomass estimates of *M. capensis* by depth stratum on the South Coast

Of particular concern currently is the direct impact longlining could have on the South Coast where, in water shallower than 200 m, it is expected to target primarily on the shallow-water Cape hake *Merluccius capensis*. Research surveys on the Agulhas Bank have shown that the biomass of *M. capensis* fluctuates seasonally and annually (Fig. 3). Further, the stock size of *M. capensis* on the South Coast is considerably smaller than that of the West Coast *Merluccius paradoxus* (the component forming the bulk of the trawl catch there). Current research therefore has put emphasis on assessing the two hake stocks separately, because the assessment in use does not separate the two species, and industry makes no attempt to differentiate between them at landing.

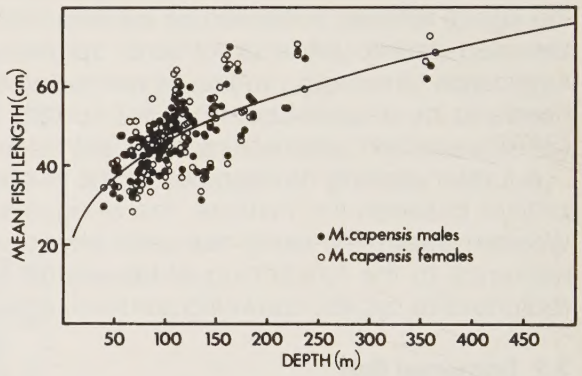


Fig. 4: Comparison of the mean length of *M. capensis* per research trawl on the South Coast, showing the increase in length with depth, but no difference between the sexes

Research has shown that *M. capensis* has a strong size-related trend with depth. The largest fish are caught in deeper water (Fig. 4) and this trend is the same for both males and females. However, the relative abundance of males and females changes with depth. Males dominate shallow water (< 100 m) and females (at a length of about 50 cm) dominate in water depths > 100 m (Fig. 5). These relationships have been identified for the trawl data only and ongoing research aims to determine whether the same selectivity pattern is likely to apply to a hake-directed longline fishery. A longline fishery targeting exclusively on the more fecund component of the hake stock is likely to have a significant impact on recruitment to any future hake fishery. However, this impact may not necessarily be negative, and the present research initiatives are looking at the effect of both trawl and longline fisheries operating together.

Demersal research also continues to focus on the valuable Agulhas sole stocks, assessment of this species continuing to be somewhat problematic. Research aims at improving understanding of the migrations of the species and, for example, the relationship between abundance and substratum type. Surveys have shown that Agulhas sole are found to depths of about 120 m, but that they are more abundant at depths shallower than 100 m. Their distribution is continuous on the central Agulhas Bank, but farther east it is patchy, sole being found mainly in the vicinity of sheltered bays. On the central Agulhas Bank, the highest densities of juveniles (10–24 cm long) are found on large mud patches and relatively few juveniles are present on sandy sediments (Fig. 6). The implication of these distribution patterns is that trawling operations on the mud patches could be an important source of mortality of juveniles.

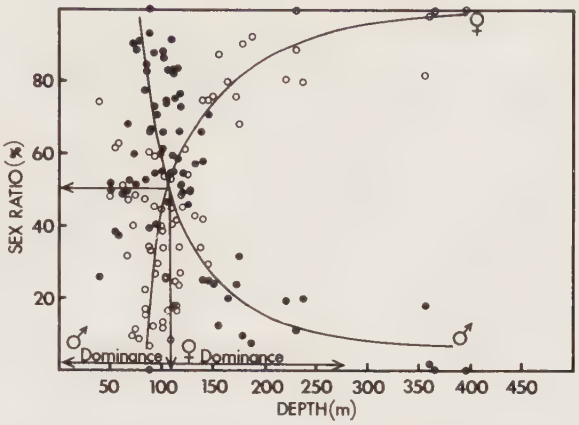


Fig. 5: Sex ratio of *M. capensis* in the research survey trawls, showing the dominance of males in shallow water and of females in deeper water

Spawning females, as determined from the presence of ovaries with post-ovulatory follicles or hydrated oocytes, are found from east of Cape Agulhas to Port Alfred (Fig. 6), mainly on sand or near the edge of mud patches. There, they spawn in the deeper water (88–108 m) of the bight between Cape Agulhas and Cape Infanta. Off Still Bay, sole spawn in water shallower than 80 m, off Mossel Bay they are present in both the shallow water of the Bay at <50 m and farther offshore to 100 m. In St Francis Bay and between Algoa Bay and Port Alfred sole spawn at depths of 50–80 m.

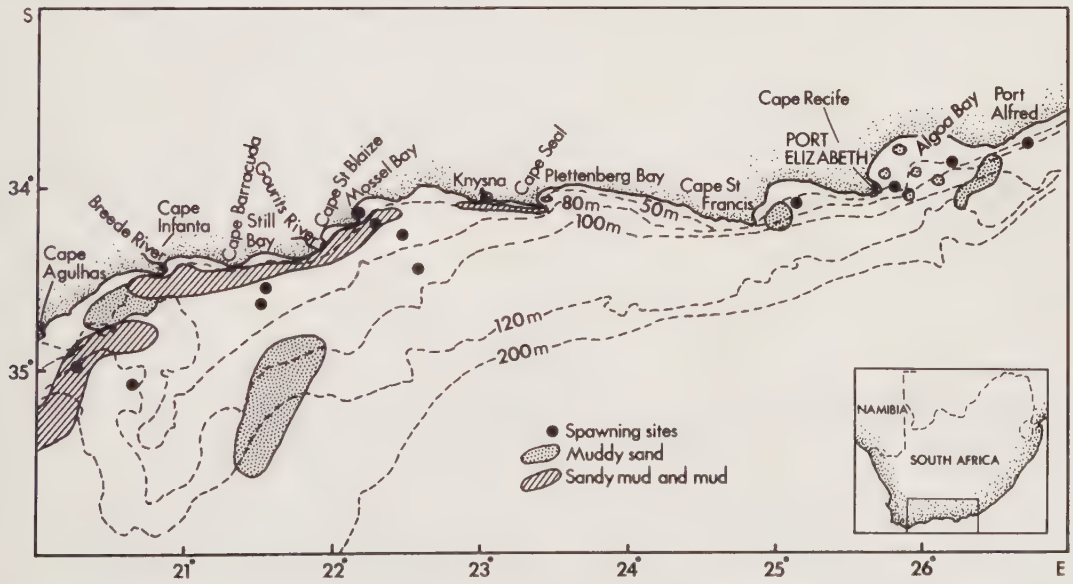


Fig. 6: The distribution of spawning Agulhas sole on the South Coast compared to the extent and location of mud patches

2.3 Linefish

THE National Marine Linefish System (NMLS) continued to provide important information on catch and effort for the commercial and recreational linefisheries. A total of almost 3 000 commercial vessels submitted monthly returns to the NMLS, reporting a total of nearly 90 000 days fished. These catch returns were supported by returns from the major fishing harbours, covering over 33 000 days fished, as well as reports from major linefish dealers, providing information on total landings in some areas. As part of a general review of the research responsibilities of the Institute, the NMLS was critically reviewed. A general questionnaire to all users reported wide support for the system, and an initial review indicates that data on the NMLS have been used to produce 275 publications since 1975, including journal papers, theses, symposium presentations, feedback pamphlets to fishermen and various informal reports.

An analysis of past and present commercial catches in Natal showed how catch per unit effort (*cpue*) has declined, and how total catches have been maintained only by switching to smaller target species and migrants from the Cape and Moçambique. A comparison of white stumpnose *Rhabdosargus globiceps* catches by linefishermen, beach-seine nets and trawlers indicated that neither sector appeared to be solely responsible for declines observed in stocks of this species from 1950 to 1980, but that excess exploitation by all sectors had coincided with poor year-classes to depress the stock. Various management recommendations were made to the South African Marine Linefish Management Association, the most important of which concerned reducing the bag limits for red steenbras *Petrus rupestris*, in an effort to halt the decline of this important endemic reef fish.

As a result of the apparently overexploited state of albacore (longfin tuna, *Thunnus alalunga*) in the southern Atlantic, a concentrated effort was made to resolve questions regarding the abundance indices and catch-at-size database for this stock. Data series for the Taiwanese and Japanese longline fisheries were revised to exclude the effect of shift in targeting to bigeye tunas, and revised production model analyses presented to the 1993 meeting of the International Commission for the Conservation of Atlantic Tunas (ICCAT) suggested that the maximum sustainable yield (*MSY*) of this resource is approximately 25 000 tons, rather than 20 000 tons as estimated in 1992. Nonetheless, combined South Atlantic catches have exceeded this level for the past five years, and it may become necessary to recommend a 25 000 ton international *TAC* for southern albacore if abundance indices continue to decline.

Research into the role of the De Hoop Marine Reserve in protecting stocks of reef fish in the South-Western Cape continued with the contracting of the University of Cape Town Statistics Department to analyse associations between various reef fish species and the physical and biotic characteristics of the reefs on which they occur. Once recognizable "reef types" have been defined, analysis will continue to compare the density and size frequency of important reef fish on the various reef types in the De Hoop Reserve and the heavily fished Vlakbank reef off Struis Bay.

Tagging of reef fish in the De Hoop Reserve also continued. Over 9 300 fish have been tagged since December 1987, of which 4 055 have been roman *Chrysoblephus laticeps*. In all, 679 tags have been returned, and return information has been used to investigate how rapidly fish move out of the reserve to supplement catches nearby. It has been found, for example, that reserves can serve as important protection areas for juvenile red steenbras,

which remain resident on inshore reefs until they mature, whereafter they move offshore to join adult shoals on the deep Agulhas banks.

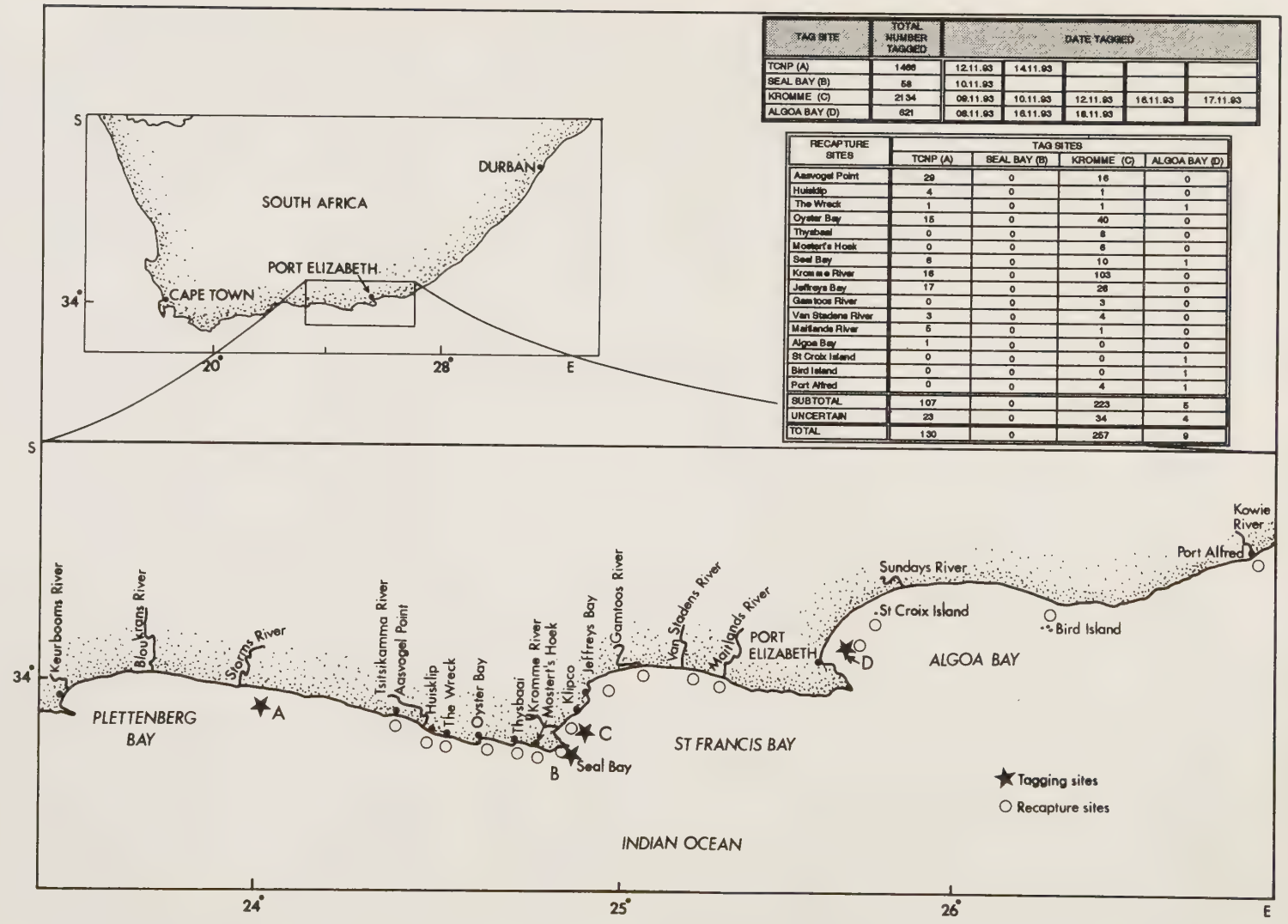
The Institute continued to oversee funding of contracted research projects at a number of other research institutes, designed to address linefish management problems in particular areas:

- The contracted collection of catch and effort data for the recreational fisheries in Natal continued under the direction of the Oceanographic Research Institute in Durban, providing the main input of recreational data to the NMLS.
- The study of the biology and management of kob, originally contracted to the Department of Fisheries Science at Rhodes University, was transferred to the Institute with the appointment to the Institute of the responsible researcher. Having determined that there are actually two separate kob species, this study then concentrated on determining the most effective management options for them. There is actually little overlap in catches, shore-anglers exploiting one species and Cape skiboaters the other, so separate management measures can probably be effectively applied to these sectors.
- The second phase of the Tsitsikamma study, also contracted to Rhodes University, continued to assess the difference between reef-fish population structure within and outside the Tsitsikamma National Park. Significant differences have been found in densities of species such as red steenbras and musselcracker *Cymatoceps nasutus*. Work under this project will continue to try and assess the role of dispersal of eggs and larvae from reserves as a mechanism for sustaining adjacent fisheries.
- The University of Cape Town completed their study of the beach-seine fishery in False Bay, aimed at quantifying the effects of this fishery on the fish resources and general ecology of the Bay. Initial analyses show that the beach-seine catches of most species are relatively small compared to national catches, but that catches of white steenbras *Lithognathus lithognathus* exceed estimated *MSY*. Further results suggest that allegations that beach-seine nets damage the seafloor, or that they catch excessive quantities of juveniles, are unfounded.
- The investigation by the University of Cape Town of the effectiveness of shore-angling management measures in the South-Western Cape continued, extending initial evaluation of the beneficial role played by large marine reserves such as the De Hoop Reserve. Traditional management measures, such as bag limits and closed seasons, seem to be relatively ineffective in the face of continually increasing participation by recreational anglers.

2.4 Squid

AFTER an intensive period of planning and design in 1991/92, good progress towards realising many of the goals of the squid research programme was made in 1993.

Among the most important of these was the first phase of the project to develop an Operational Management Procedure for chokka squid *Loligo vulgaris reynaudii*. Two expert-system type workshops were held, the final product of which was a set of decision rules which enable structured and consistent decisions to be made on the duration of the closed season. The rules were constructed on the basis of the evaluation of various criteria, including the results of the spring biomass survey and the catch in the first seven months of the year. These



TAG SITE	TOTAL NUMBER TAGGED	DATE TAGGED				
TCNP (A)	1466	12.11.93	14.11.93			
SEAL BAY (B)	58	10.11.93				
KROMME (C)	2134	09.11.93	10.11.93	12.11.93	16.11.93	17.11.93
ALGOA BAY (D)	621	09.11.93	16.11.93	18.11.93		

RECAPTURE SITES	TAG SITES			
	TCNP (A)	SEAL BAY (B)	KROMME (C)	ALGOA BAY (D)
Aasvogel Point	29	0	16	0
Huisklip	4	0	1	0
The Wreck	1	0	1	1
Oyster Bay	15	0	40	0
Thysbaai	0	0	8	0
Mosterl's Hoek	0	0	6	0
Seal Bay	6	0	10	1
Kromme River	16	0	103	0
Jeffreys Bay	17	0	28	0
Gamtoos River	0	0	3	0
Van Stadens River	3	0	4	0
Maitlands River	5	0	1	0
Algoa Bay	1	0	0	0
St Croix Island	0	0	0	1
Bird Island	0	0	0	1
Port Alfred	0	0	4	1
SUBTOTAL	107	0	223	5
UNCERTAIN	23	0	34	4
TOTAL	130	0	257	9

Fig. 7: Chokka squid tag/release and recapture sites during a migration study in 1992/93 on the South-East Coast (TCNP = Tsitsikamma National Park)

decision rules were applied in the 1993 recommendation for chokka squid management. The search for improved criteria (e.g. the relationship between catches and environmental variables) is being continued, and the procedure will be refined and re-evaluated on a regular basis as the time-series of available data grows. In the meantime, industry support the system currently in place, having played a role in its development.

Stock assessment projects have also made good progress and an overview of current achievements was published during the year. Further, the trawl surveys on the shelf produced estimates of biomass, and the F.R.S. *Algoa* cruise in November 1993 provided a comprehensive evaluation on the suitability of the hydroacoustic method for estimation of squid biomass. With regard to the latter, the result was negative, but hydroacoustics were found to be extremely useful in studies of individual spawning aggregations. At the same time tagging has also come to the fore as a useful tool, and a combination of methods which includes trawling, hydroacoustics and tagging are likely to provide better estimates of overall and spawning biomass.

Tagging has been one of the striking successes of the chokka squid research programme. Apart from its usefulness in stock assessment, it is being used to study migration patterns and stock identity (Fig. 7), estimate mortality, study aggregating behaviour and help validation of squid ageing by means of statoliths.

The age and growth project has resulted in the development of a new ageing technique, and enough data have been accumulated for the validation of readings, which continues in earnest.

A simulation model is also being developed for the chokka squid jig fishery. The data available for this resource consist of time-series of commercial and research catches and effort, providing the basic information from which to model the dynamics of the stock and its response to fishing mortality. Once completed, this model will be used to investigate the impacts and benefits of various management strategies to determine the optimum approach for the resource and fishery.

There are other aspects of the research which are benefiting from the dynamic approach being applied to the squid programme. New challenges, such as the extent of spawning in deep (>100 m) water, a feeding/mortality link in paralarvae, and the role of the Tsitsikamma National Park in management of the resource are being addressed with this principle in mind.

2.5 Abalone

MONITORING of recruitment cycles at four stations within the major abalone *Haliotis midae* fishing grounds as well as within a marine reserve remains a major commitment. This work continues to show successful settlement at the three sites east of Cape Hangklip, but intermittent or low-intensity settlement at Robben Island on the West Coast. This is hopefully an indication that the reproductive success of abalone in the important commercial grounds east of Cape Hangklip is not being affected adversely by commercial harvesting. The monitoring programme will be continued indefinitely because it should provide a vital "early warning" signal for the fishery and resource in the event that recruitment failure should occur.

For the second year running, telephonic polling of licensed recreational abalone divers yielded valuable insight into this previously unknown aspect of the fishery. Permit sales continued to escalate, reaching over 34 000 for the 1992/93 season. From the telephonic

interviews made by a contracted independent survey company, it is estimated that over 480 tons of abalone were taken by recreational divers during that season, and the average take was, as in the previous year, 20 abalone per permit-holder. Using this useful statistic, it is possible to back-calculate and to estimate theoretical recreational landings prior to the telephone surveys by using permit sale figures. A more realistic picture of historical abalone landings is now possible (Fig. 8). The recreational sector of the fishery is clearly a highly significant component of the fishery, and it is apparently growing, with major implications regarding the management of the resource as a whole. Although monitoring of indices such as *cpue* and size composition show the fishery to be currently healthy, it would clearly be unwise to allow continued escalation of one sector of the fishery, while controlling the other sector by means of a *TAC*. Various options for limiting the recreational fishery have been considered, but this delicate management issue has still to be resolved satisfactorily.

A size-based model of the abalone resource is nearly complete, and ultimately it will allow the estimation of key population dynamics parameters such as natural mortality, initial biomass and equilibrium recruitment (Fig. 9). The model will be used to determine the impacts and benefits of various management strategies to the resource and fishery.

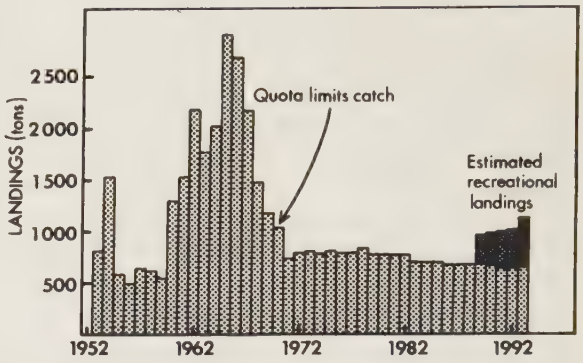


Fig. 8: Abalone commercial and estimated recreational landings

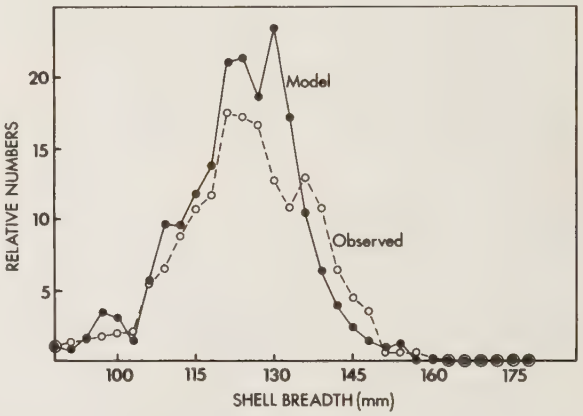


Fig. 9: Size frequency of the Betty's Bay abalone population (observed), plotted with the estimated size frequency (model) fitted with a size-based abalone model. This fit was produced with an annual survivorship value of 0,93

2.6 Rock lobster

GROWTH and production rates of West Coast rock lobster continued to be low on most grounds during 1993. After intense scientific debate, the minimum size for the 1993/94 commercial fishing season was reduced to 75 mm carapace length and the corresponding *TAC* set at 2 200 tons, with the retention of a mixed sex fishery. These management decisions have been guided by a size-based model of the resource. The model has been used to project forward for 20 years and to ascertain the maximum *TAC* which can be realized for a given minimum size, under an assumed two additional years of low growth before recovery, without violating two constraints. These constraints are that the harvest proportion must not exceed 30% and that the egg production must remain above 50% of an agreed reference level. There are, however, some concerns about the approach, including uncertainties

regarding the relationship between pristine egg production and the reference level, the likely duration of the slow growth phase and the absence of a feedback control in the existing procedure. Work has been done, and is continuing, into trying to obtain a better estimate of the true abundance of females at the end of the 19th century, so that the true extent of the decline in egg production up to now can be ascertained. While there is general agreement among scientists as to the magnitude of recent fluctuations in growth rate, the present phase of slow growth appears to be unprecedented and there is accordingly no way of telling how long it will last. This uncertainty arguably represents the greatest problem facing managers of the resource. The annual fisheries independent monitoring survey (FIMS), successfully introduced last year, should form the basis for the introduction of feedback control into the management procedure, helping to overcome aspects of the uncertainties discussed above.

Damage to undersized lobsters during commercial fishing operations has been a cause for concern. A reduction in the number of undersized lobsters reaching the surface during commercial fishing operations (i.e. better sorting of the catch by lobster traps) would reduce the potential for limb loss and discard mortality. After in-depth consultation with both fishing industry representatives and lobster fishermen and preliminary trials with various trap designs, two new trap designs were selected for further testing. Both of these designs incorporate escape bars in place of the retaining bag of 60 mm mesh and require modification rather than replacement of the existing standard 100-mm mesh traps. One design involves the replacement of the mesh bag with a metal framed basket (covered on the sides with 60-mm mesh) with a bottom grid of 42-mm escape gaps. The second trap design is similar to the first except that 44-mm escape gaps are used in the bottom grid and trap length is kept similar to that of the standard traps by the movement of one of the side entrances. The results of 45 trap hauls with each design (24-h soak times) in a commercially fished area showed that the first and second experimental traps caught 38 and 55% less undersized lobsters and 16 and 11% more size lobster than the control (standard traps) respectively. These highly encouraging results will hopefully lead to the acceptance of a new design by industry and the phasing-in of the new trap over the next few fishing seasons.

The telephone survey designed to establish the quantity of lobsters harvested by recreational permit-holders was repeated in 1992/93. This survey was of particular interest because it highlighted the effects of the reduction in lobster minimum size (89 mm to 80 mm carapace length) and the increased length of the recreational fishing season on recreational lobster fishing. Over 58 000 permits were issued over the 1992/93 season, representing an increase of approximately 30% over the previous season. The combination of decreased minimum size and increased duration of recreational lobster fishing season resulted in each permit-holder catching on average 23 lobsters in the 1992/93 season, compared to only 10 in the previous season. The total recreational catch in 1992/93 was estimated at 470 tons, an increase of c. 200% on the 160 ton estimate for 1991/92 season.

Research into lobster growth rates and growth prediction continued in 1992/93. Results from research into the relationship between male growth and female fecundity collected over a six-year period in six different fishing areas suggest that fast or slow growth in any one year is a coast-wide phenomenon and that this might therefore make female fecundity a good predictor of male growth, which takes place some six months after the females become ovigerous. The work will continue, but more emphasis is to be placed on the utilization of biochemical changes in the lobster hepatopancreas as a predictor of male growth.

A range of surplus production models was fitted to the catch and effort data from 1973 to 1991/92 for South Coast rock lobster *Palinurus gilchristi*. However, uncertainties precluded the use of these models in the *TAC* assessment. Future trends in this fishery will be monitored closely.

2.7 Seaweed

THE agar-producing red seaweed *Gracilaria* is being studied at Saldanha Bay (Fig. 10), where it continues to wash ashore in commercial quantities. An explanation for the periodic collapse of this resource is now being sought by examining the bacterial pathogens of *Gracilaria*, work being carried out in collaboration with the University of Cape Town. Central to this research is an understanding of the seasonal water conditions (temperature, nutrients, etc.) that may induce disease in the seaweed. The summer of 1993/94 brought to Saldanha Bay an unexpected bloom of the nuisance macrophyte, *Ulva lactuca*, usually associated with eutrophic conditions. This outbreak had significant socio-economic implications because it threatened the viability of the *Gracilaria* collection industry. It both displaced the *Gracilaria* from part of its range and contaminated the wash-ups. Rotting *Ulva* also causes an offensive smell, and removing the seaweed from beaches is very expensive. Results from the mariculture-related Saldanha Bay System Programme permitted the development of a model which explained the occurrence of the *Ulva*. Follow-up detailed sampling and isotope analysis of *Ulva* samples connect the required high nitrogen to the discharge of organic waste from the fish factories in the Bay. These research findings begin to deal with what will in the future become an increasingly prevalent problem, that of conflicting use of marine systems, in this case bays.

Fig. 10: A *Gracilaria* growth experiment at Saldanha Bay is examined by a University of Fort Hare student during a vacation job with the Institute. Summer growth rates often exceed 10% per day, i.e. the seaweed doubles its mass in less than 7 days

Studies of the effects of experimental harvesting of kelp (for abalone-feed) at Danger Point have entered their second year. Although the understorey community has so far been largely unaffected by harvesting, regrowth of the kelp canopy has been poor. When current experiments end, a reappraisal of "cleared-lane" harvesting may be necessary. It is thought that kelp recruitment is being severely limited by herbivores (particularly sea urchins — Fig. 11). In kelp beds west of Cape Point, there are far fewer sea urchins and kelp recruitment rates

Fig. 11: At Danger Point, grazing by numerous sea urchins strongly affects the structure of subtidal communities and appears to limit the recruitment of new kelp plants after harvesting

are high. Future experiments will further explore this interesting geographical contrast in kelp/grazer dynamics.

The carrageenan-producing red seaweed genus *Gymnogongrus* was recently split into two genera on the basis of life history characteristics. A critical re-examination of this, using molecular methods and southern African species, is being carried out in collaboration with researchers in the U.S.A.

Contract research on the harvesting ecology of the red seaweed *Porphyra* is being carried out at the University of Cape Town. The genus is sought for abalone feeding and possibly as human food (it is widely eaten in the East). Biomass and seasonal studies are underway, but the discovery that several species are involved has complicated the study, and some effort is being directed at problems of field identification.

* * *

3. HIGHLIGHTS OF SUPPORTING RESEARCH

3.1 Monitoring coastal sea surface temperature and wind

A NETWORK of monitoring stations (Fig. 12) spanning the region from Port Nolloth to Sodwana Bay (the latter in conjunction with the Oceanographic Research Institute [ORI] in Durban) has been established. Bottom-moored temperature recorders gather information on nearshore sea temperatures at these sites. The data have served as input to research into rock-lobster growth and behaviour patterns, red-tide monitoring, interannual environmental variability, squid spawning and coral reefs. Data from these recorders on the South Coast, together with coastal wind data, highlighted the relative failure of coastal upwelling during the summers of 1991/1992 and 1992/1993, during the extended Pacific *El Niño*/Southern Oscilla-

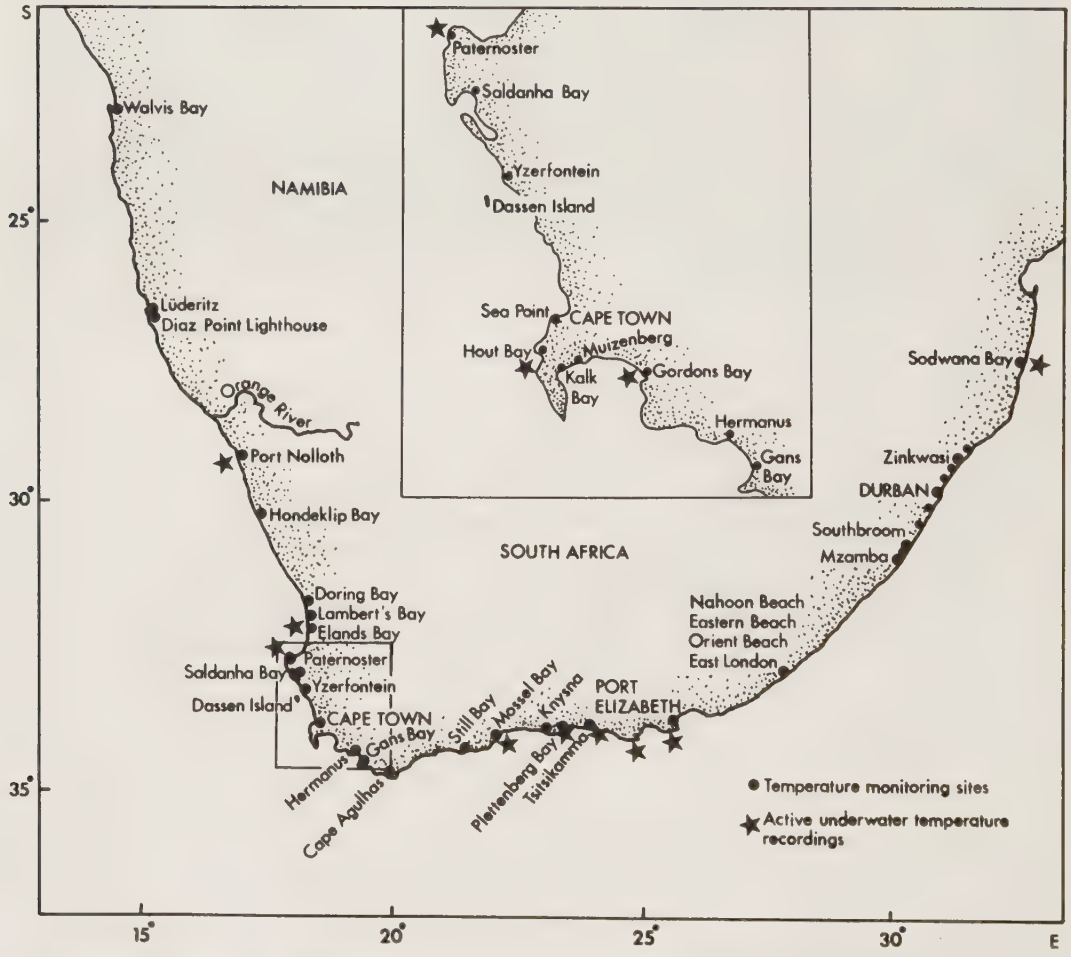


Fig. 12: Locations of temperature monitoring sites used in the preparation of the data report and of active underwater temperature recorders

tion event. The data show clearly the recent return to more normal summer conditions, with strong easterly winds driving vigorous upwelling. For example, the mean sea temperatures at Tsitsikamma during February 1992 and February 1993 were 19,6 and 21,9°C respectively, whereas February 1994 had a mean of only 13,7°C.

A data report was compiled on existing sea surface temperature records from harbours and other points around the shores of southern Africa (Fig. 12). That data set and the temperature recorder data set have been put to good use in answering queries from industry on wide-ranging issues, for instance about suitable salmon-, abalone- and prawn-farming sites and about resort development, as well as in answering enquiries from the tourism board.

3.2 Organic loading of Table Bay by sewage

THE discharge of organic-rich effluents into bays is, under certain physical conditions, the main factor behind the worldwide problem of eutrophication in the vicinity of urban areas. Its consequences, low oxygen and nuisance algae, some of which lead to toxic red tides, pose risks to potentially beneficial economic use of those marine systems, such as mariculture. There was concern that the policy of discharging sewage through the Green Point (Cape Town) outfall would aggravate an existing natural eutrophication situation as a result of upwelling. The use of the stable isotope ratio of nitrogen ($\delta^{15}N$) allowed the first ever direct assessment of the fate and accumulation and hence eutrophication potential of nitrogen in Table Bay sediments. A mixing model was used to establish the relationship between the quantity of nitrogen in the sediments and its source. The results from a two-year study showed that the Green Point outfall contributed less than 1% of the organic loading in Table Bay and that the present total organic loading into this system poses a low risk of eutrophication.

3.3 Low-oxygen mass mortality

THE development of a massive phytoplankton bloom dominated by the dinoflagellates *Ceratium furca*, *Prorocentrum micans* and the toxic *Alexandrium catenella* accompanied an abrupt end to the typical summer conditions of strong upwelling during the latter part of February 1994. The following months were characterized by a general relaxation of surface pressure gradients owing to the merging of low pressure cells off the South-West Coast during transitions in synoptic weather patterns. The consequent light onshore winds resulted in the shoreward transport of the dinoflagellate bloom, giving rise to a spectacular red tide extending over hundreds of kilometres of the West Coast.

Although only a minor component of the bloom, *A. catenella* rendered shellfish toxic at several localities on the West Coast, and for the first time since the inception of mussel farming in 1984, the mussel industry in Saldanha Bay was forced to discontinue harvesting following positive tests for Paralytic Shellfish Poisoning.

Entrapment and decay of the bloom in St Helena Bay in early March 1994 was responsible for the most extensive anoxic water mass and the highest water column concentrations of hydrogen sulphide yet recorded in the area. The rapid sinking of planktonic detritus is believed to have caused further depletion of oxygen in the seasonally-depleted bottom waters, maintaining bottom oxygen concentrations at $< 0{,}5$ m$\ell \cdot \ell^{-1}$ for several weeks. The event was also evident from records of a continuously monitoring dissolved-oxygen sensor

in Elands Bay. Data for the period 12 February 1994 to 31 March 1994 are superimposed on a similar dissolved oxygen record obtained in 1993 (Fig. 13), and it is apparent that levels of dissolved oxygen in the bottom waters at the monitoring site were considerably lower for most of the 1994 period (mean 2,79 $m\ell \cdot \ell^{-1}$) than they were in 1993 (mean 4,59 $m\ell \cdot \ell^{-1}$).

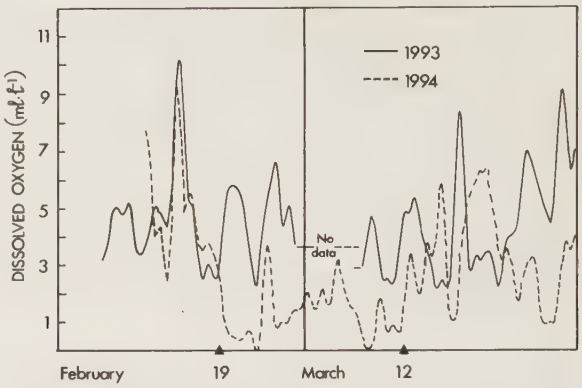


Fig. 13: Dissolved oxygen in February/March of 1993 and 1994 derived from an oxygen probe in Elands Bay

The shortage of oxygen and the poisoning by hydrogen sulphide, generated by anaerobic bacteria in the absence of dissolved oxygen, were responsible for the largest ever recorded mass mortality of fish and rock lobsters on the West Coast. Estimated mortalities included 60 tons of rock lobsters and 1 500 tons of fish. Approximately 50 species of dead fish were identified. The mullet *Liza richardsonii* formed the bulk of these fish mortalities (1 250 tons) and bottom-dwelling fish dominated the remaining 250 tons. A diving survey in April confirmed the virtual absence of rock lobsters at traditional fishing sites in the area and the presence of large numbers of dead mussels on the bottom. A box core taken at a frequently sampled site in St Helena Bay indicated that almost all of the burrowing fauna in the upper sediment layers had died. This may have an effect on juvenile demersal fish, which are thought to prey on some of the in-fauna, but the effect should not be prolonged because indications are that bottom oxygen concentration might already have returned to normal levels.

3.4 Saldanha Bay system programme

THE past year witnessed the start of a three-year interdisciplinary and inter-Institute (Sea Fisheries Research Institute, University of Cape Town, Rhodes University and EMATEK, Stellenbosch) programme that aims to provide the means by which Saldanha Bay can be managed, by determining its carrying capacity for industrial-scale mussel production. Results obtained during the first year have already led to a review of previous models of the dynamics of the Bay as well as the development of new insights. One such example is the highly dynamic nature of the physical coupling of the Bay with the shelf upwelling dynamics. An hourly temperature record from the bottom layer of the monitoring station in Saldanha Bay (Fig. 14) shows that there is an important synoptic-scale variability in the depth of the thermocline associated with the inflow and outflow of cold upwelled water from outside the Bay. The periodicity of this dynamic process is approximately $6\frac{1}{2}$ days, a timing which corresponds with the frequency of upwelling wind events. The implication is that there exists a previously unaccounted for flushing mechanism that may turn out to be more important than either tidal or wind-forced exchange at the coastal boundary. It will have clear implications for both nutrient and phytoplankton input-output as well as ventilation of the Bay.

This type of environmental programme will achieve two important products: it will constrain the environmental risk factors (natural and human impacts) associated with investments in shellfish aquaculture in Saldanha Bay, and it will provide a prototype approach for similar

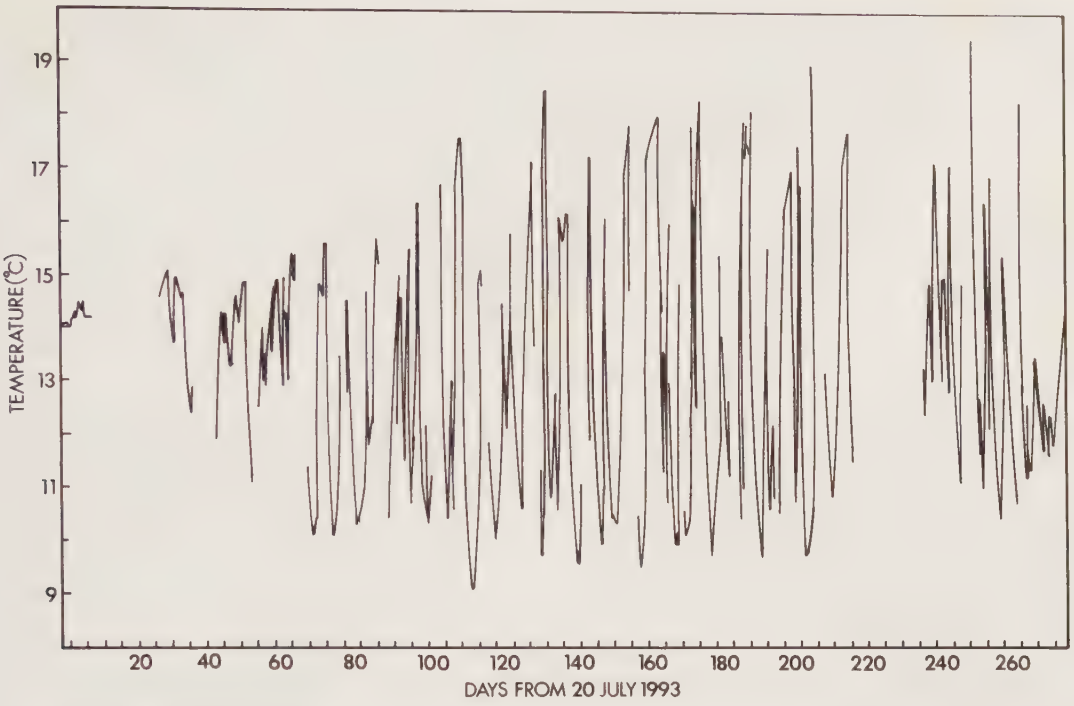


Fig. 14: Hourly temperature record of the bottom layer of Saldanha Bay for the period July 1993 – April 1994

ventures in the future elsewhere in southern Africa as marine aquaculture expands to other areas and to other forms such as finfish.

3.5 Coupling of biological and physical processes

TWO models aimed at bridging the gap between biological and physical processes were constructed, one being designed to look at the drift of pelagic eggs and larvae spawned on the Agulhas Bank and moving up the West Coast, the other a model to examine possible causes of low-oxygen water on the West Coast.

The physical component of the pelagic drift model uses a prescribed static current field which is randomly perturbed on short scales of time and space to simulate diffusion and on longer scales of time and space to simulate dynamically chaotic processes such as filaments and eddies, which are characteristic of continental shelves but have no deterministic expression. Preliminary results concerning biomass transport and successful recruitment, using a current field constructed from Acoustic Doppler Current Profile (ADCP) surveys, show that the most significant feature is the barrier effect of the shelf-edge jets on the western Agulhas Bank. These inhibit the loss of eggs and larvae to the deep sea.

The two-layer oxygen model was constructed for the West Coast between the Olifants and Orange rivers, bracketing the 30–180 m isobaths. It is a simple budgetary model which includes the transfer of gas across the surface interface and thermocline, benthic consumption, and consumption by "raining" material in both the upper and lower layers. The periodic

production of oxygen following upwelling episodes is filtered and entered as a small contribution with seasonal variation. The gas-transfer process, which is a function of wind speed, is now well understood and can be accurately modelled. Oxygen levels in the lower layer show a slow response to both wind speed and seasonal erosion of the thermocline. It is critically dependent on benthic consumption. The model diagnosed a "crash" in the lower layer concentration during the reduced wind conditions of 1985-1987, with only a small increase in benthic consumption. For critical values of this parameter, a slow recovery of up to a year is predicted. The model assumes that water enters the region from the north in the form of the poleward undercurrent. Time-dependent adjustments can be made to the concentration in this boundary process.

3.6 Feeding ecology and energetics of pilchard

LABORATORY experiments of the feeding ecology of pilchard have included assessments of feeding behaviour, feeding, rates of respiration and excretion, and assimilation efficiencies. These data will allow construction of a bioenergetics model, essentially a balanced equation describing energy intake and use. The model can be used to predict fish consumption and growth under different environmental conditions and can therefore enhance management strategies. Moreover, a detailed knowledge of the pilchard's feeding ecology also allows comparison to be made with that of anchovy.

Experiments have shown that pilchard are primarily filter-feeders, capable of sieving out very small food particles such as diatoms and microzooplankton. When filter-feeding, pilchard swim in a tight school with their mouths open wide and their opercula markedly flared. Pilchard are also capable of size-selective particulate feeding, or biting, on larger, individual food particles. The change from filter- to particulate-feeding is dependent upon particle size, particles larger than 1 230 µm eliciting a biting response at low concentrations, but eliciting a filtering response if present at high concentrations (Fig. 15). Similarly, anchovy are also capable of both filter- and particulate-feeding, but the switch from filtering to biting occurs at a smaller particle size of approximately 720 µm. In contrast to pilchard, anchovy do not filter-feed on particles larger than 720 µm, even if these are present in high concentrations. Pilchard are much more efficient than anchovy at removing small (e.g. phytoplankton and microzooplankton) particles from the water column, whereas anchovy, which are predominantly particulate-feeders, remove large particles (e.g. large copepods and euphausiids) more effectively.

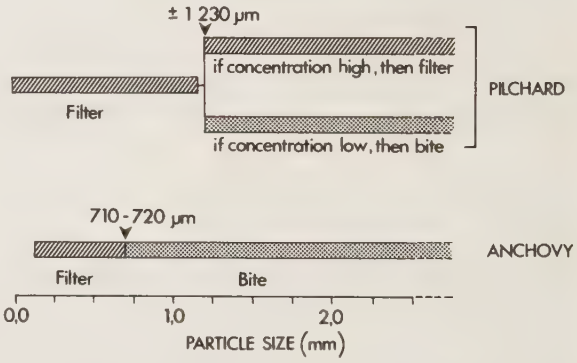


Fig. 15: Schematic representation of feeding behaviour as related to food particle size for pilchard and anchovy

The energetic costs of each feeding mode are determined by measuring the respiration rates of the fish during non-feeding, filter-feeding and particulate-feeding activities. When the relationships between respiration rate and swimming speed for pilchard in each of these activity states are compared (Fig. 16), the slope of the predicted respiration rate/swimming

speed regression is greatest for particulate-feeding. This indicates that the fish consume more oxygen per unit increase in swimming speed during particulate-feeding than in any other activity state, and that particulate-feeding is energetically the most expensive feeding mode. This is surprising, because one would assume that the wide flaring of the opercula when filter-feeding would greatly increase drag compared to the more streamlined shape of a non-feeding or particulate-feeding fish. Increased drag raises the energetic cost of swimming, as is the case for filter-feeding anchovy where this is the more expensive feeding mode. However, viscous forces, which are proportional to fish surface area and result in drag, are not the only forces acting upon a swimming fish. Inertial forces, which are proportional to fish mass, also affect the dynamics of swimming. The contrast in relative energetic costs of the two feeding modes between anchovy and pilchard, filter-feeding being energetically cheaper for pilchard and particulate-feeding being cheaper for anchovy (Fig. 17), may be due to the different relative importance of viscous and inertial forces for each species.

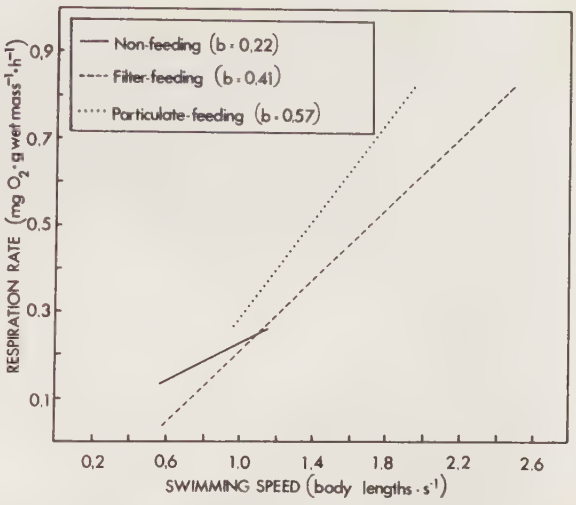


Fig. 16: Predicted regressions of respiration rate as a function of swimming speed for pilchard engaged in non-, filter- and particulate-feeding activity states. The slopes of the regression equations are given in the key

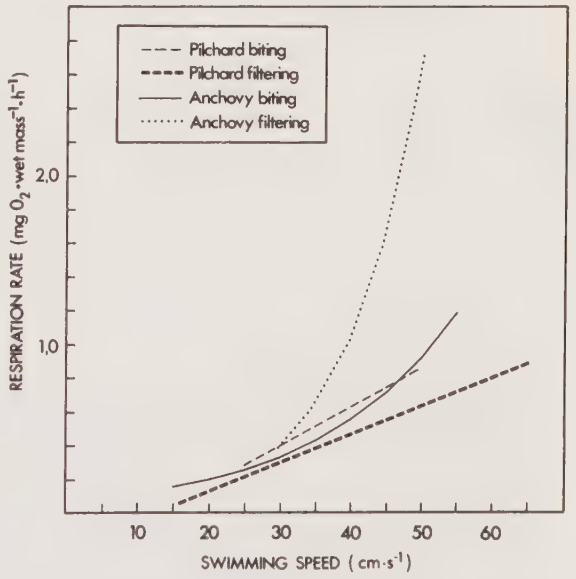


Fig. 17: Predicted regressions of respiration rate as a function of swimming speed for pilchard and anchovy during filter- and particulate-feeding

3.7 Age determination of pelagic fish

SUCCESSFUL management of fish resources requires that the age structure of exploited stocks is analysed regularly. At the Institute, ageing of pelagic fish is based solely on otoliths, the most accurate method. Age determination is done at two levels of precision. For stock assessment, the age in years is adequate, whereas age validation, back-calculation of seasonal spawning intensities and recruitment predictions require a much higher resolution, as provided by daily ring counts.

The size of the otoliths, their "readability" and consequently the methods used are dependent on the species. To age anchovy, pilchard and round herring *Etrumeus whiteheadi*, whole otoliths are used. To obtain the age in years, the number of zones containing one opaque (white) and one translucent (hyaline) ring

Fig. 18: Otolith of a 2-year-old anchovy. A wide opaque (white) band and a small translucent (dark) ring constitute the first annual growth zone (A1). A false ring (F) is deposited after age 1

(annulus) each are counted on the lateral surfaces of the otoliths (Fig. 18). Changing environments may, however, produce additional false zones or sometimes cause a suppression of the first annual zone. Otolith zones are frequently measured in order to compare their sizes with previously determined annulus sizes. Larger-growing otoliths of longer-lived species, e.g. horse mackerel *Trachurus trachurus capensis*, need to be baked and/or sectioned, because the annual zones are obscured by multiple rings or by overgrowth after

Table I: Age-length key for anchovy sampled during the spawner biomass survey in November 1993

Standard length of fish (cm)	Number per year-class					Total otoliths read
	92/93	91/92	90/91	89/90	88/89	
8,0	10	32				42
8,5	8	71				79
9,0	8	48				56
9,5	11	43	3			57
10,0	13	50	25	1		89
10,5	3	46	53			102
11,0	3	31	90	7		131
11,5	2	20	81	6		109
12,0		16	59	7	1	83
12,5		4	43	8		55
13,0		2	18	3		23
13,5			7			7
14,0			1			1
Total	58	363	380	32	1	834

age 6 (approximately 37 cm fish length). In 1993, the consistency of the ageing performance of individual readers was quantified for the first time by comparing different readers and different readings by the same reader, using anchovy otoliths. Experienced readers in South Africa can age fish with a precision of 2–3% of the age value.

The increment width between the last annual zone and the otolith margin provides an estimate of the fractional age in excess of the completed years. The fractional age allows one to back-calculate the approximate birthdate season and so enables each individual to be placed in a year-class (Table I). This method is used for anchovy and pilchard, particularly when two or more peak spawning periods have occurred in a season, and when an assessment model requires year-class strength as an input parameter. From this method, it was revealed that the 1992/93 year-class of anchovy was very weak. As a consequence, the *TAC* of anchovy for 1994 was set considerably lower than for 1993.

The ageing results for important species are compiled in monthly or annual age-length keys. The proportion of each age-group in each length-class multiplied by the number of fish

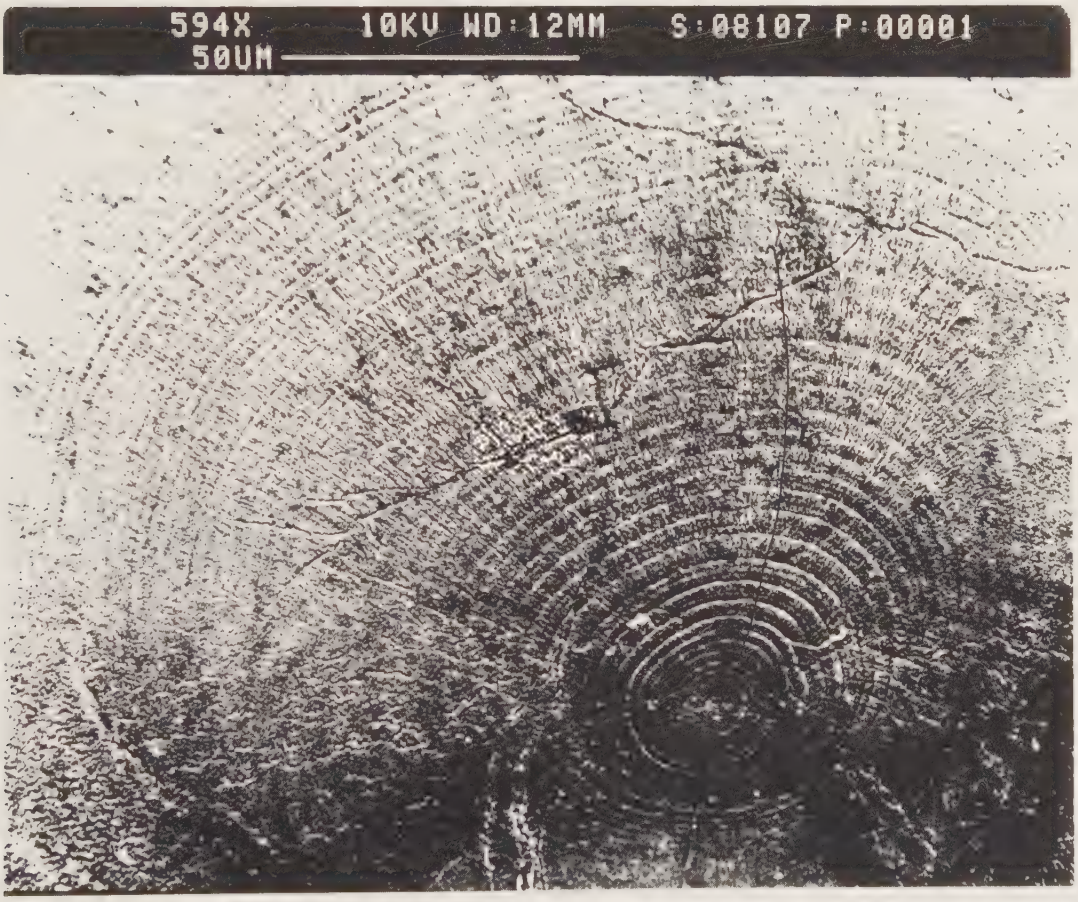


Fig. 19: Photograph of the centre of an anchovy otolith, as viewed under a Scanning Electron Microscope. Each circular structure around the core represents one daily ring

in each length-class and summed over all length-classes provides an estimate of the age composition of the stock. If the otolith samples are taken from commercial landings, as for pilchard, the age composition reflects only that part of the stock removed by the fishery.

To determine actual age, it is important to verify the annuli as such. Daily rings (Fig. 19) provide an independent means to validate the ages. Daily ring counts are now being used to verify the annual zones in anchovy otoliths and another project aims at the verification of the annuli in pilchard, round herring and horse-mackerel otoliths. The growth of the otolith's dimensions in anchovy and pilchard is also being investigated; otolith dimensions are independent estimators of age and they also serve to discriminate between consecutive recruiting year-classes and between subcohorts within a year-class. These validation procedures reduce age misclassifications and so increase the accuracy of the assessment procedures.

Daily ring counts also serve to compare the growth performance of recruits younger than 1 year. A comparison of anchovy recruits collected in the years 1985, 1989, and 1991 showed that growth rates were considerably slower (0,30–0,32 mm·day^{-1}) in 1989 and 1991 than in 1985 (0,40 mm·day^{-1}), resulting in markedly smaller lengths at the same age. At present, daily ring counts are also used to back-calculate the hatchdate distribution of anchovy recruits in order to estimate the duration and the number of peak spawning periods and the spawning intensities. The aim of this project is to make recruitment predictions for certain environmental and spawning scenarios.

3.8 Oil-to-meal ratios of pelagic fish

SINCE the inception of the purse-seine fisheries off South Africa and Namibia in the early 1950s, monthly records of the quantities of fish oil and meal produced by the fish reduction

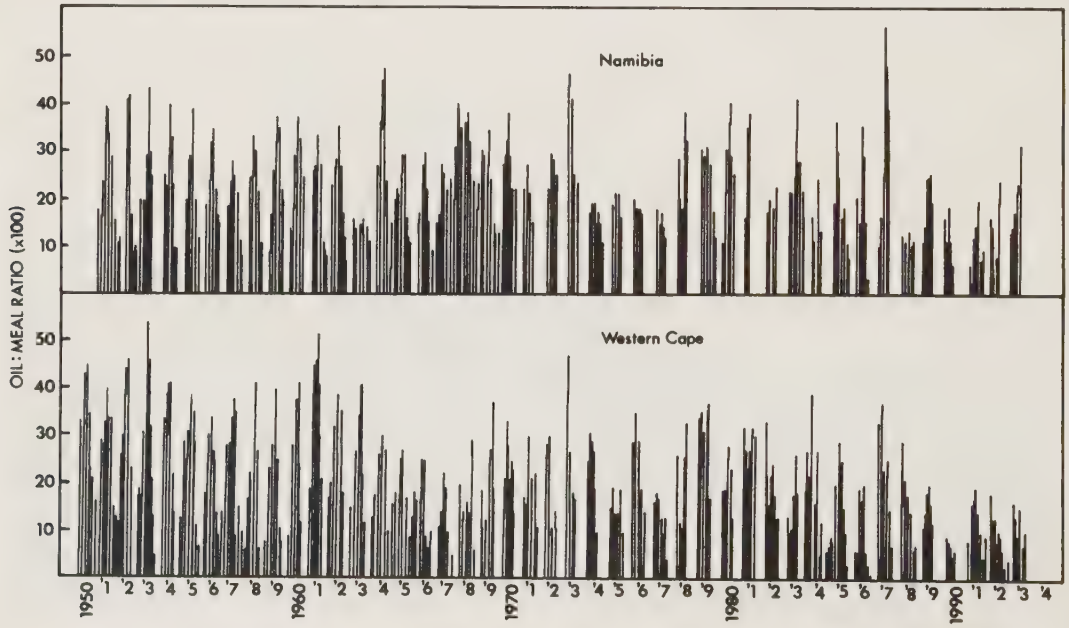


Fig. 20: Monthly oil-to-meal ratios of pelagic fish in the northern and the southern Benguela ecosystem, 1950–1993 (* = January)

plants have been kept (Fig. 20). The data have now been analysed statistically and the main results include the following:

- Oil-to-meal ratios show clear seasonal cycles, peaking in March/April off the Western Cape, but two months later in early June off Namibia. Such cycles are taken to reflect the quality of feeding conditions for the fish as well as the transfer of energy reserves for spawning.
- All the main West Coast ports from Walvis Bay to Hout Bay show a highly significant downward trend in the oil-to-meal ratios within the period 1950–1993. Furthermore, seasonal cycles were far more pronounced in earlier years than more recently.
- Certain years, such as 1973 and 1987, stand out in the records of Namibia and each West Coast port, suggesting the existence of large-scale influences on the Benguela ecosystem, whereas other events (such as the Benguela *Niño*s of 1963 and 1984) are only reflected in the records from Namibia in the northern system.
- Examples are given where both annual and medium-term (3–5 year) anomalies in the oil-to-meal records appear to have provided evidence of favourable or unfavourable conditions for the reproduction of pelagic fish.

3.9 Sardine and anchovy recruitment programme

OWING to the availability of the Institute's newly purchased and refurbished F.R.S. *Algoa* in mid 1993, the Sardine and Anchovy Recruitment Programme (SARP) was commenced in August. The programme is being undertaken jointly by the Institute and the Benguela Ecology Programme. The long-term goal of SARP is to be able to forecast recruitment of 6-month-old anchovy (and pilchard) to the commercial fishery, from knowledge of conditions on the spawning grounds the previous summer. The sampling objectives are therefore to determine the monthly variations in the number of fish eggs produced throughout the summer spawning period, the relative proportion of prerecruits reaching the nursery grounds on the West Coast, and the environmental factors which may affect these processes, e.g. ocean currents and availability of food to spawning adults and the young larvae. Week-long cruises were conducted every month from August 1993 to March 1994, and recruitment results will be validated against the results of the survey of anchovy recruits in May 1994, when data on the birthdate distributions were obtained. Patterns observed in the distributions can be related back to monthly variations observed in egg abundance and larval growth, availability of planktonic food, condition of the adults and larvae, and current transport.

Preliminary analysis indicates consistent upwelling throughout summer 1993/94. In January 1994, for example, cold water (12°C) was found inshore along the entire western Agulhas Bank. Very few adult anchovy or pilchard were found in the region, possibly accounting for relatively low abundance of eggs over a large proportion of the season. Histological studies on the reproductive condition of adult anchovy showed that spawning started in late August, and indications were that the spawning rate would be low in the following months. Information on ocean currents indicates that current patterns were generally consistent with observations from previous studies. On the western Agulhas Bank, north-west currents were evident. The jet current flowed strongly northwards between the Cape Peninsula and Cape Columbine, and appeared to have an onshore component north of Cape Columbine. The majority of eggs spawned on the western Agulhas Bank were therefore likely to have been transported to the nursery grounds on the West Coast.

3.10 Patterns of vertical movements in demersal fish

USING combined acoustic and trawling observations with information on diet and feeding periodicity, it appears that patterns of foraging and vertical migratory movements of hake and horse mackerel differ markedly. Hake move into midwater to feed, but they forage individually and not as a population, returning to the bottom when sated. Because of this asynchronous feeding behaviour, a variable proportion of the hake population would be close to the bottom during the night, and owing to the inherent inability of acoustic systems to resolve near-bottom fish populations, the usefulness of such techniques for estimating their population size is limited. On the other hand, the nocturnal ascent of horse mackerel into midwater, which seems to be for reasons other than feeding, operates at the population level, facilitating the use of acoustic techniques for estimating their abundance. These results substantiate the belief that adequate information on fish behaviour, particularly on vertical migration and foraging strategies, is a necessary prerequisite for effective acoustic survey design.

Observations suggest that thermal conditions may influence the nocturnal depth of horse mackerel in the water column. Horse mackerel on the Agulhas Bank migrate more extensively into midwater under conditions of strong thermoclines, an observation that helps to explain

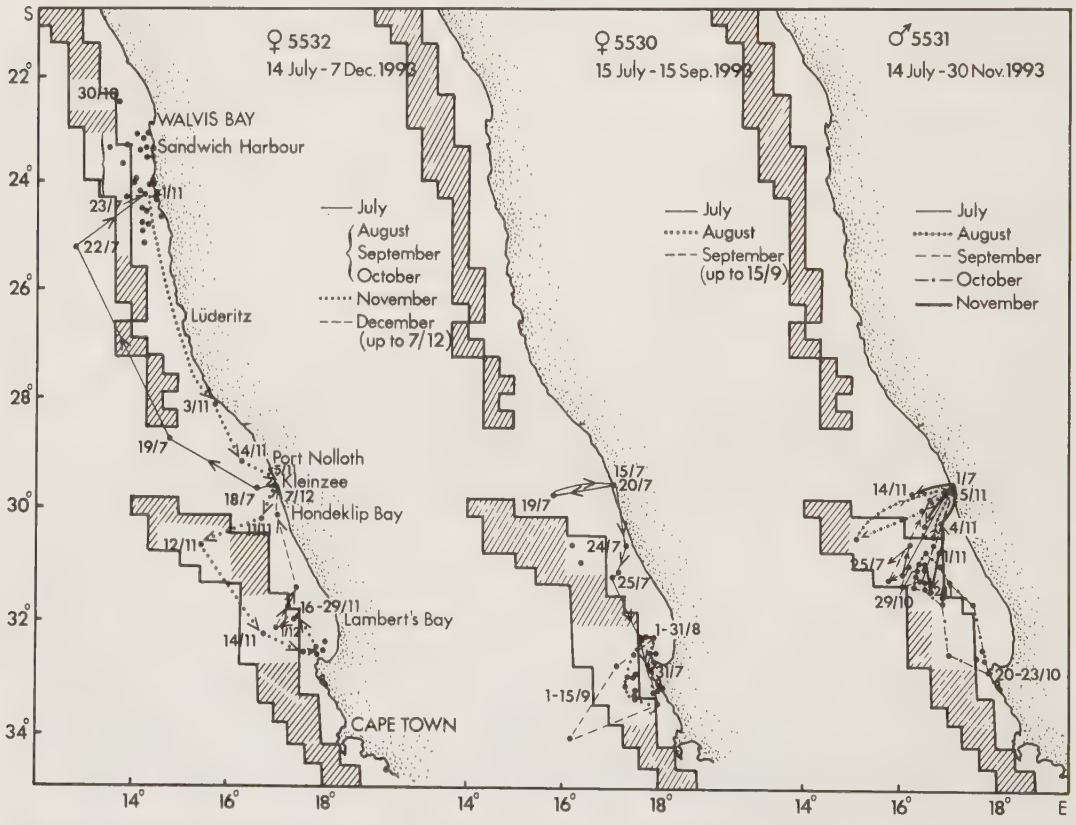


Fig. 21: Tracks of (a) Female Seal 1 from 14 July to 7 December 1993, (b) Female Seal 2 from 15 July to 15 September 1993, (c) Male Seal 1 from 14 July to 5 December 1993. The hatched area shows the extent of the demersal trawling grounds in South African waters

why horse mackerel are generally more readily available to midwater trawlers on the eastern Agulhas Bank, where the thermocline is consistently strong and shallow, than on the western Bank, where the thermocline is deep and isothermal conditions are common, especially during winter. Future studies will explore the hypothesis that horse mackerel prefer to migrate vertically into warm surface water at night, after feeding ceases.

3.11 Satellite tracking of seals

THE large size of the South African fur seal *Arctocephalus pusillus pusillus* population (currently 1,5 – 2 million animals) has led to conflict with the fishing community, because fishermen believe that seals consume large quantities of commercial fish as well as interfering with some fishing operations. Recent analysis of seal feeding habits suggests that some seals may eat discarded trawler offal, such as undersize hake, and it is possible that they have learned to follow trawlers in order to pick up free food. If so, it is important to know to what degree this is happening, for these "freeloaders" are consuming dead or moribund fish, which do not represent any loss to the industry.

It is therefore necessary to be able to follow seals at sea, a hitherto impossible task. However, the newly developed satellite-linked time-depth-recorder has enabled this problem to be tackled. The instrument can be fitted to a seal and beams radio signals to a satellite, which automatically computes its position. During 1993, two females and one male were fitted with satellite-linked recorders. These animals fed in widely separated areas on the West Coast, but only the male showed much evidence of feeding near trawlers (Fig. 21). The project will be continued in 1994.

3.12 Diet of Cape gannets

THE Cape gannet *Morus capensis* is one of southern Africa's endemic seabirds. It breeds at three coastal islands off Namibia and three off South Africa, preys on shoaling fish hunted by the purse-seine fleet and is sensitive to fluctuations in the abundance of such fish.

The diet of Cape gannets has been monitored on a monthly basis at the two breeding localities off western South Africa since 1978. The 15-year record has several interesting features. The quantity of anchovy in the diet has fluctuated substantially, with an extended period of low contributions in 1989 and 1990 (Fig. 22) coincident with a much reduced biomass of anchovy off South Africa. Anchovy were important in the diet in 1991 and 1992, but their contribution decreased again in mid

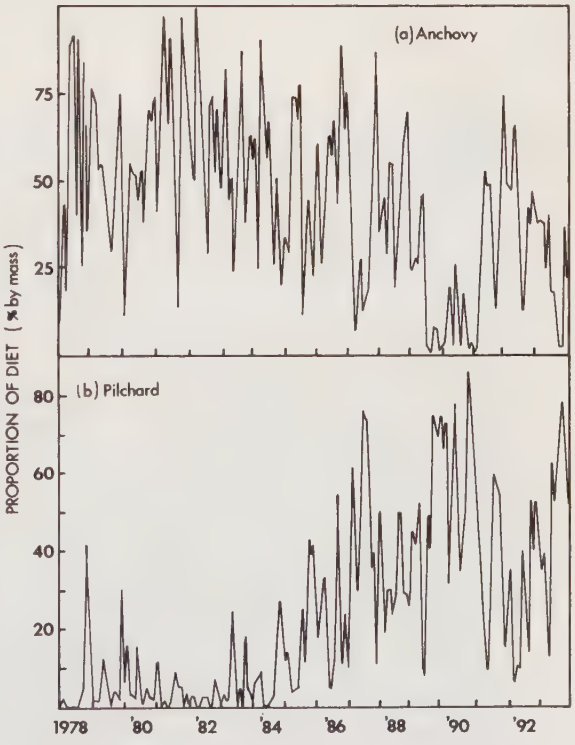


Fig. 22: The contribution of (a) anchovy and (b) pilchard to the diet of Cape gannets off western South Africa, January 1978 – December 1993

1993, indicative of their reduced availability as prey. The November acoustic ship-borne survey confirmed the decreased abundance of anchovy.

The contribution of pilchard to the diet increased markedly over the 15-year period (Fig. 22), and it has been especially important in years of poor availability of anchovy.

Numbers of Cape gannets at Lambert's Bay have increased since 1978 (Fig. 23). At Malgas Island, numbers increased following proclamation of the island as part of the West Coast National Park in 1985, when guano scraping was terminated, but decreased again in 1990 when anchovy was scarce.

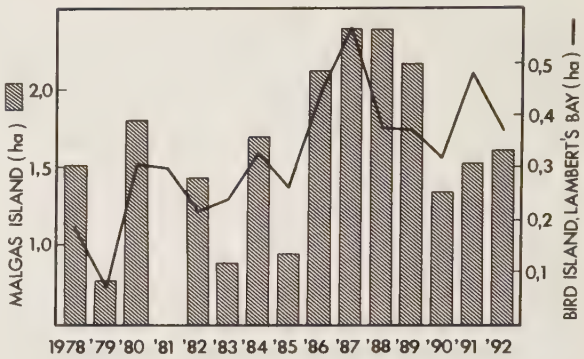


Fig. 23: Area occupied by Cape gannets at Malgas Island and Bird Island, Lambert's Bay, 1978–1992. Aerial photographs were taken during the breeding season, except in 1979 when they were taken in winter

3.13 Antarctic krill research

THE Institute undertakes research on Antarctic krill *Euphausia superba* as part of South Africa's commitment to the Commission for the Conservation of Antarctic Marine Living

Fig. 24: R.F.A. *Diligence* and F.R.S. *Africana* at Grytviken Harbour, South Georgia

Resources and to assess the species' resource potential. A major highlight in 1993/94 was a joint cruise by the Institute's F.R.S. *Africana* and the British Antarctic Survey (BAS) vessel R.R.S. *James Clark Ross* to study krill aggregation dynamics around South Georgia. This is the first time an Institute vessel has cooperated with a British vessel in foreign waters and also means that *Africana* has now carried out surveys on all the current krill fishing grounds. Figure 24 is of the *Africana* and the British Naval Auxiliary Vessel *Diligence* at South Georgia.

The cruise results indicated a scarcity of krill, an observation supported by contemporaneous studies by BAS scientists on the breeding failure of many krill predators feeding around South Georgia. Preliminary analyses suggest that the lack of krill may be attributed to an unseasonal occurrence of warm water (> 3°C) around the island, probably as a consequence of water intrusion from the north and reduction in outflow from both the Scotia and Weddell seas. Combined with a lack of krill observed by U.S. scientists farther south, it seems that both a failure in recruitment and in the hydrographic transport of adult krill from the south has impacted heavily on krill stocks at South Georgia.

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4. ADVANCES IN ACOUSTIC TECHNOLOGY

DURING the course of the year, the Institute's new research vessel, F.R.S. *Algoa*, was equipped with split-beam scientific echo-sounders and AIDA, the Institute's echo-integration and *in situ* target-strength determination system, making her acoustically compatible with F.R.S *Africana*. The first acoustic survey on *Algoa* was carried out successfully in August.

Work is continuing on the identification and isolation of echoes from single fish, an essential and problematic process in the estimation of target strength *in situ* where densities are high, such as in pelagic fish aggregations. Full-scale tank tests with model targets and field observations have revealed serious shortcomings in conventional single-target recognition techniques. These have been largely overcome by applying more stringent recognition criteria, leading to the target-strength-length relationship for anchovy shown in Figure 25. Application of this relationship to anchovy survey data collected over the past 10 years leads to far better agreement between acoustic and egg-production estimates of spawner biomass than was obtained using the previous relationship, which was one published in 1983 for Icelandic herring. The current method is being improved further, which is expected to lead to the refinement of Figure 25 and the first reliable target-strength relationship for South African pilchard.

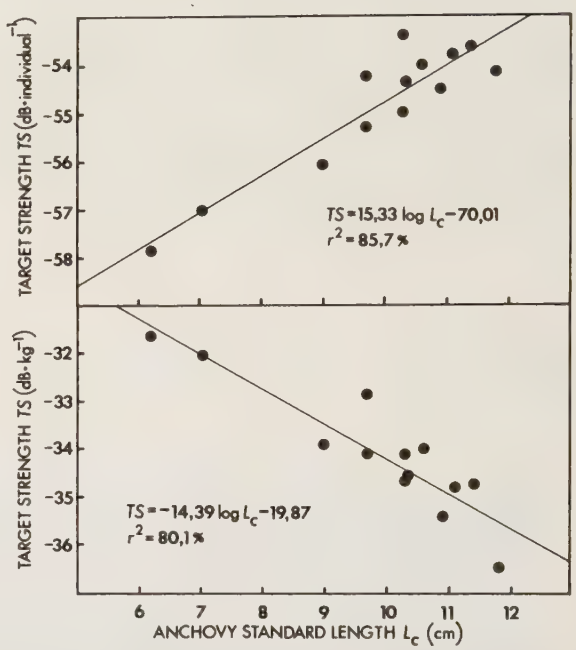

Fig. 25: Two formulations of the relationship between anchovy target strength and fish length obtained by *in situ* measurements

Good progress has been made in the development of the multi-beam echo-counter (code-named ABACUS) described in last year's Research Highlights. The primary aim is to produce a swath of high-frequency narrow beams with a resolution high enough to count individual fish at densities well beyond the limit for *in situ* target-strength determination, permitting density to be estimated in situations where the target strength cannot be determined. A prototype receiver has been constructed and is currently being tested.

In another development, software has been written for recognizing and characterizing fish and zooplankton aggregations according to acoustic information on their dimensions and structure. This is the first step in the development of objective criteria for classifying automatically the various types of biological target encountered during acoustic surveys.

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5. PUBLICATIONS

IN the period of 28 years since 1966, which year marks the first revival of the *Fisheries Bulletin* series, this Institute and its predecessors have been associated with more than 2 200 published works, at a mean of 79 per year. The number of publications has doubled each decade, 12% of the grand total being produced in the first, 29% in the second and 59% in the last one, of which only eight years have yet been completed. Moreover, there has been a steady increase in each publication category, namely in-house, other local and overseas. However, the mix of publication categories has changed. In the first decade most (48%) were published in-house, 30% in other local media and 22% in other countries. In the second decade more were channelled to other local and overseas media (30% each). In the past incomplete decade even more went to other local media (44%), but there was a partial restoration of in-house publication (35%) at the expense of publication abroad (22%).

In 1993 Sea Fisheries had a hand in 185 publications, which is close to the mean of the past five years of 187 and 13 more than in 1992. In 1992, in-house publications dominated with 53% because of the inclusion of contributions to the second symposium of the Benguela Ecology Programme held in 1991, but in 1993 other local publications formed the majority (56% of the annual total) because 74 advance abstracts of staff contributions to the eighth South African National Oceanographic Symposium are included in the listing hereafter.

In-house publications this year consisted of 29 papers in *South African Journal of marine Science* **13** (only nine with staff involvement), eight contributions by staff to the booklet on the pelagic zone published with the sponsorship of a fishing company for National Marine Day and a booklet on red tide, the second in the series of popular works.

Of the 185 works listed, 66% were written by staff, 23% were done in cooperation with non-staff (mostly local) and the remainder were contributed to the Journal by other local (16 papers) and overseas (3 papers) scientists, one paper being a cooperative effort by non-staff locals and an overseas scientist. In 1992 non-staff scientists contributed more papers to the Journal (50) and overseas writers were involved in half of those, the reason being the international nature of the symposium of the Benguela Ecology Programme listed for that year.

The contributions listed now were the work of 172 different authors (84 staff, 64 other local and 24 overseas). The composition of the 208 authors in 1992, namely 74 staff, 76 other local and 58 from overseas, again shows the difference between the two major symposia listed in the two years. If the identity of authors is left out of account, the total authorship of the 185 papers in 1993 amounted to 381 (261 staff, 90 other local and 30 overseas). As usual, most (57%) of the authors this year were involved in a single paper, involvement gradually decreasing to one staff author who had a hand in 10 papers. Similarly, most (46%) of the papers had a single author, multiple authorship decreasing steadily to five papers each with six authors and one each prepared by nine and 13 authors.

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